

# **PREDICTION OF PRIMARY FRAGMENTATION CHARACTERISTICS OF CASED MUNITIONS**

**MICHELLE M. CRULL, PHD, PE**

U.S. Army Engineering & Support Center, Huntsville

ATTN: CEHNC-ED-CS-S

P.O. Box 1600

Huntsville, AL 35807-4301

Telephone: (256) 895-1653

Fax: (256) 895-1602

E-Mail: [Michelle.M.Crull@HND01.usace.army.mil](mailto:Michelle.M.Crull@HND01.usace.army.mil)

## **ABSTRACT**

Safety to the public and nearby operational personnel during unexploded ordnance (UXO) operations is of the utmost importance. An accidental explosion produces hazards from primary fragments, blast overpressure, ground shock, and noise. The effects used to determine withdrawal distances for UXO operations are predominantly blast overpressure and primary fragmentation. For most ordnance the fragmentation range is much larger than the inhabited building distance (IBD) for blast overpressure. In order to determine the withdrawal distance for primary fragmentation, the fragmentation characteristics of the munition must be determined.

The Structural Branch of the U.S. Army Engineering and Support Center, Huntsville (USAESCH) uses methods described in TM 5-1300, "Structures to Resist the Effects of Accidental Explosions" to determine the fragmentation characteristics of cased, cylindrical munitions. These characteristics include initial fragment velocity, weight of the largest fragment, average fragment weight, the total number of fragments, and the fragment weight for a given confidence level.

These methods are applicable only for primary fragments resulting from a high-order detonation of a cylindrical casing with evenly distributed explosives in direct contact with the casing. For casings that are not uniform in thickness or diameter along the entire length, the casing must be modeled using a series of equivalent cylinders. The method is a trial-and-error procedure involving iterating on geometry to match the total modeled explosive weight to the actual explosive weight.

These calculated fragmentation characteristics are used for a wide variety of purposes such as fragment range, striking energy, areal debris density and fragment penetration. The calculation methods, some modeling tips, and an example are presented.

## **1.0 INTRODUCTION**

The U.S. Army Engineering and Support Center, Huntsville (USAESCH) is currently engaged in projects which require detection and removal of buried ordnance. Safety to the public and personnel performing removal operations nearby are of the utmost importance. An accidental

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>AUG 1998</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1998 to 00-00-1998</b>	
4. TITLE AND SUBTITLE <b>Prediction of Primary Fragmentation Characteristics of Cased Munitions</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>U.S. Army Engineering &amp; Support Center, Huntsville,ATTN: CEHNC-ED-CS-S,P.O. Box 1600,Huntsville,AL,35807-4301</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM001002. Proceedings of the Twenty-Eighth DoD Explosives Safety Seminar Held in Orlando, FL on 18-20 August 1998.</b>					
14. ABSTRACT <b>see report</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>8</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

explosion produces hazards from primary fragments, blast overpressure, thermal effects, ground shock and noise.

The Structural Branch, USAESCH, uses methods described in TM 5-1300, “Structures to Resist the Effects of Accidental Explosions” to determine the fragmentation characteristics of fragmenting munitions. These characteristics include initial fragment velocity, weight of the largest fragment, average fragment weight, weight of a fragment using a prescribed confidence level, and the total number of fragments.

This paper outlines the methods detailed in HNC-ED-CS-S-98-1, “Methods for Predicting Fragmentation Characteristics of Cased Munitions.” The modeling technique and fragmentation characteristics described in this document are developed in accordance with TM 5-1300. HNC-ED-CS-S-98-1 has been approved by the Department of Defense Explosives Safety Board (DDESB) “for use in deciding Inhabited Building Distance (IBD) for primary fragments in site remediation activities.” Use of these methods will ensure uniformity in the calculation of fragmentation characteristics of UXO and aid in the standardization of safety submissions for UXO remediation.

This paper details the methods used to determine the fragmentation characteristics. An example, using these methods, is included. Some of the uses of these fragmentation characteristics are discussed. Blast overpressure, thermal effects, ground shock and noise from an accidental explosion are not addressed in this paper.

## 2.0 THEORY

The fragmentation characteristics are calculated using the methods described in TM 5-1300 Section 2-17.2. The methods described are for the high-order detonation of a munition with a cylindrical casing or one modeled by a series of cylinders as described in Section 3.0. The technique used for calculating the initial fragment velocity,  $v_o$ , is the Gurney method.

$$v_o = (2E')^{1/2} \left[ \frac{W / W_c}{1 + 0.5 W / W_c} \right]^{1/2} \quad (\text{TM5 - 1300, Eq. 2 - 32})$$

where  $(2E')^{1/2}$  = Gurney velocity of explosive, ft/sec (see TM 5-1300, Table 2-5)

$W$  = 1.2 x actual charge weight, lbs

$W_c$  = weight of casing, lbs

“The fragmentation pattern and the weight of the largest fragment resulting from the high-order detonation of an evenly-distributed explosive in a cylindrical metal case of uniform thickness have been calculated according to relationships developed on the basis of theoretical considerations confirmed with a large number of tests.” [TM 5-1300] The weight of the largest fragment is given by:

$$W_f = [M_A \ln(8W_c/M_A^2)]^2 \quad (\text{TM5 - 1300, Eq. 2 - 38})$$

and

$$M_A = B t_c^{5/6} d_i^{1/3} (1 + t_c/d_i) \quad (\text{TM5 - 1300, Eq. 2 - 37})$$

where

$W_f$  = design fragment weight, oz.

$M_A$  = fragment distribution factor

$B$  = Mott scaling factor,  $\text{oz}^{1/2} \text{ in}^{-7/6}$  (see TM 5-1300, Table 2-7)

$t_c$  = average casing thickness, in.

$d_i$  = average inside diameter of casing, in.

The total number of fragments,  $N_T$  is calculated by:

$$N_T = 8 W_c / M_A^2 \quad (\text{TM5 - 1300, Eq. 2 - 39})$$

The average fragment weight can be calculated.

$$\overline{W_f} = 2 M_A^2 \quad (\text{TM5 - 1300, Eq. 2 - 40})$$

The weight of a fragment corresponding to a prescribed confidence level ( $C_L$ ) is given as:

$$W_f = M_A^2 \ln^2(1 - C_L) \quad (\text{TM5 - 1300, Eq. 2 - 42})$$

The number of fragments with weight greater than  $W_f$  is:

$$N_f = N_T (1 - C_L) \quad (\text{TM5 - 1300, Eq. 2 - 44})$$

It should be noted that these equations are not applicable to casings designed to fragment in a specific pattern.

### **3.0 MODELING OF MUNITION FOR FRAGMENTATION CHARACTERISTICS CALCULATIONS**

The equations discussed above are designed to determine the characteristics of primary fragments resulting from a high-order detonation of a cylindrical casing with evenly distributed explosives. A cylinder is the most common shape of cased explosives. However, there may be a large variation in the thickness and the outside diameter of the casing along the length of the munition. In such cases, the cylinder is divided into a series of equivalent cylinders.

If the variation in thickness/diameter is slight, the fragmentation characteristics may be calculated using average values over the entire length of the casing. However, if the variations are large, the casing is treated as a series of equivalent cylinders representing the actual shape as closely as possible. Using the average casing thickness and diameter of each section, the fragmentation characteristics of each section may be determined. In most applications, the worst case fragmentation characteristics of the equivalent cylinders are then taken as the fragmentation characteristics of the entire casing. Certain applications such as the calculation of the range to no more than one hazardous fragment per 600 square feet consider the contribution from each region of the munition rather than the worst case fragment.

A typical munition casing is shown in Figure 1. It should be noted that the base of the munition is not part of the cylindrical shape and the fragmentation characteristics of the base may not be determined using the equations described above. Similarly, the fuze well may not contain explosive material and, if this is the case, the fragments from this region may not be characterized by the methods described above.

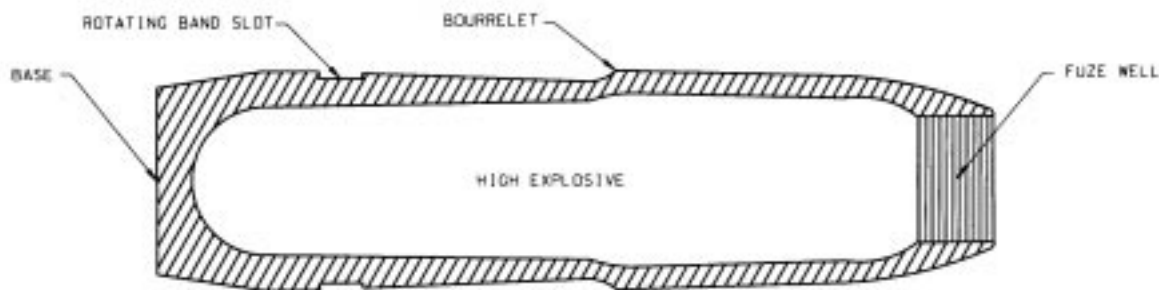


Figure 1 – Typical Munition Casing

To model a munition such as that shown in Figure 1, the munition should be divided into several regions. A new region should be described anywhere that there is a sharp change in the outer diameter such as found at the bourrelet.

Another place where the case should be divided into separate regions is where there is a change in the case thickness. For example, looking at Figure 1, it can be seen that the thickness is approximately constant from the base to the rotating band slot. From the rotating band to the bourrelet the thickness varies approximately linearly. From the bourrelet to the fuze well there is some slight variation in thickness and the outer diameter varies. At the least, such a munition should be divided into three regions (equivalent cylinders). Each cylinder should have the average thickness and average outer diameter over its length.

Another consideration when modeling the munition should be the explosive weight of the munition. It is important that the model contains the same total explosive weight (within 0.5%)

as the actual munition. Beginning with a model determined from the casing geometry, the weight of the explosive in the model may be calculated from the inside volume of the equivalent cylinders and the density of the explosive. If the total model explosive weight is not equal to the actual explosive weight, the model should be adjusted. This may require dividing the case into more regions to better describe the munition geometry.

It is important to obtain the best description of the case that is available. Ideally, a fully dimensioned drawing can be obtained. As well as matching the model explosive weight to the actual explosive weight, the model case weight should match the actual case weight as nearly as possible. Depending on the detail of the information available on the case, it may not be possible to precisely determine the actual case weight. However, by taking care to match the diameter and the thickness of each region of the model to the actual diameter and thickness of that region it is possible to obtain a reasonably accurate case weight.

If it is necessary to adjust the model case in order to match explosive weights, the first revision of the model may include dividing the case into more regions. This is especially true if the original model contains a relatively long region. Examination of the equation for the fragment distribution factor shows that the case thickness has more effect on the fragment characteristics than the case diameter. Therefore, if the model geometry in a region is adjusted to match explosive weights, the diameter should be adjusted slightly rather than the thickness.

## **4.0 EXAMPLE – 105 MM M1 PROJECTILE**

### **4.1 MODEL GEOMETRY**

The geometry of the 105 mm M1 projectile is shown in Figure 2. This geometry was obtained from unclassified drawings and descriptions in a variety of source documents. The 105 mm M1 projectile contains 5.08 lbs of Composition B high explosive.

The geometry of the model used to calculate fragmentation characteristics of the 105 mm M1 projectile is also shown in Figure 2. The 105 mm M1 projectile has three distinct zones of geometry: 1) the region between the base and the top of the rotating band, 2) the region between the top of the rotating band and the upper bourrelet, and 3) the region between the upper bourrelet and the fuze well.

The region between the base and the top of the rotating band is 3.21 inches long and has an average thickness of 0.67 inches. The average outer diameter is 4.13 inches. This is designated Region A.

The region between the top of the rotating band and the upper bourrelet is 4.76 inches long and has an average thickness of 0.52 inches. The average outer diameter is 4.13 inches. This is designated Region B.

The region between the upper bourrelet and the fuze well is 5.64 inches long and the outer diameter varies from 4.13 inches to 2.94 inches. Because of the large variation in diameter, this region is divided into two regions of equal length and average properties for each region are

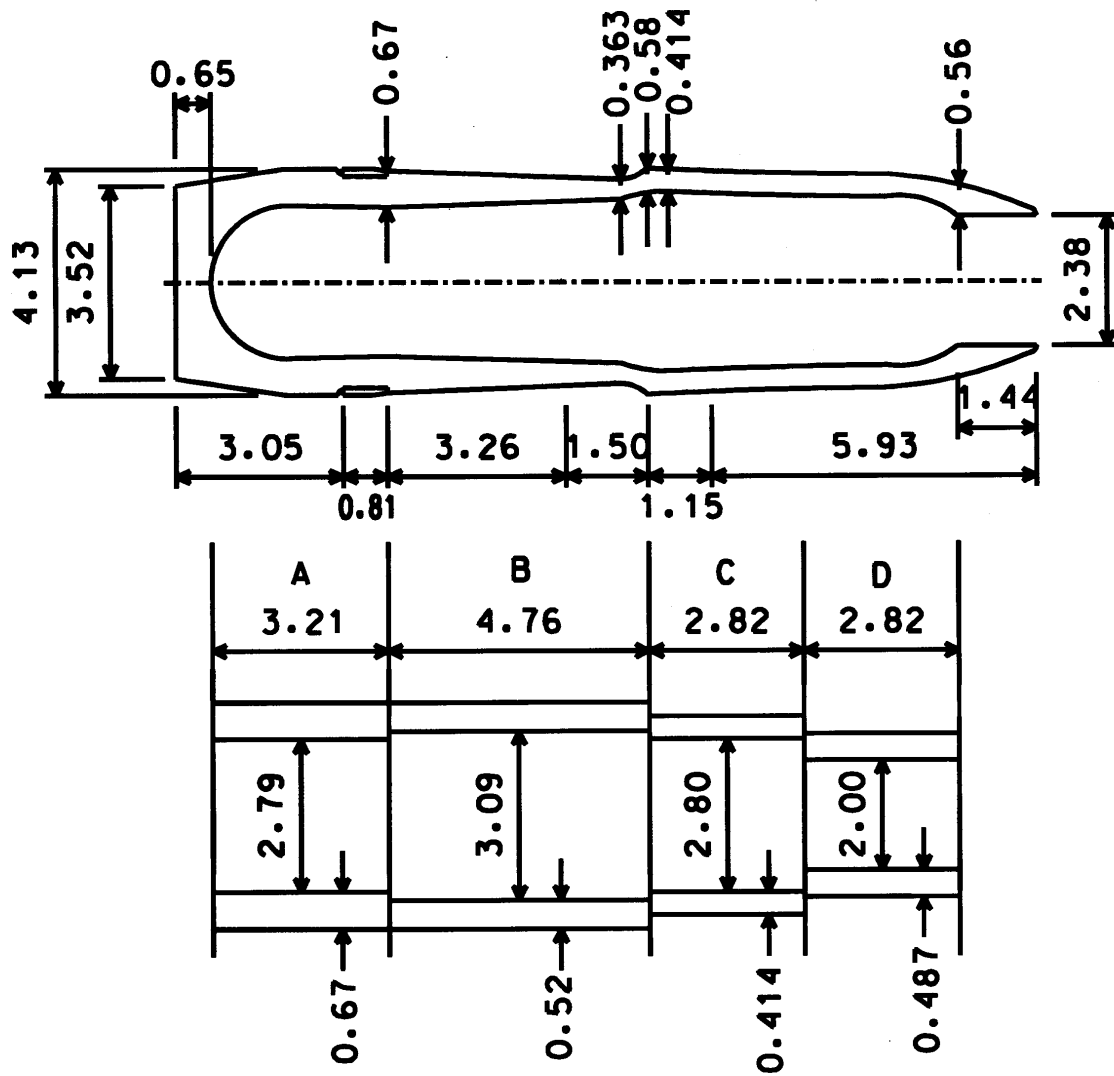


Figure 2 – 105 mm M1 Projectile and Model Geometries

calculated. Region C is 2.82 inches long and has an average thickness of 0.41 inches and an average outer diameter of 3.62 inches. Region D is 2.82 inches long and has an average thickness of 0.49 inches and an average outer diameter of 2.98 inches.

The base and the fuze well are not modeled. The method used determines the fragmentation characteristics of a cylinder (or a series of cylinders) filled with high explosive. The base may be fragmented or it may remain in one piece, this method cannot predict which. The fuze well is not filled with high explosive and does not fit the method either.

A summary of the model geometry and the explosive and case weights of each region is listed in Table 1. Note that the total modeled explosive weight is 5.06 lbs, this is 0.4% less than the actual explosive weight of 5.08 lbs. As part of the modeling process, the diameters of Regions C and D were adjusted to achieve a geometry which contained a total explosive weight within 0.5% of the actual explosive weight.

<b>TABLE 1 - 105 mm M1 Fragmentation Model Geometry</b>							
Region	Length (in)	Thickness (in)	Outer Diameter (in)	Inner Diameter (in)	Inner Volume (in <sup>3</sup> )	Explosive Weight (lbs)	Case Weight (lbs)
A	3.21	0.67	4.13	2.79	19.62	1.22	6.64
B	4.76	0.52	4.13	3.09	35.70	2.22	7.97
C	2.82	0.41	3.62	2.80	17.36	1.08	3.31
D	2.82	0.49	2.98	2.00	8.86	0.55	3.07

## 4.2 INITIAL FRAGMENT VELOCITY

Using the model geometry summarized in Table 1, the initial fragment velocity is calculated using the Gurney method. The Gurney energy for Composition B is 9100 ft/sec [TM 5-1300]. The initial fragment velocity for each region is listed in Table 2.

## 4.3 FRAGMENT SIZE AND NUMBER

The total number of fragments, the weight of the largest fragment, the average weight fragment and the weight of the 95% confidence level fragment is calculated using the Mott-Gurney equations [TM 5-1300]. The Mott scaling constant for a mild steel case and Composition B is  $0.222 \text{ oz}^{1/2} \text{ in}^{-7/6}$  [TM 5-1300]. These fragment characteristics are listed in Table 2.



<b>TABLE 2 - 105 mm M1 Fragment Characteristics</b>					
Region	Initial Fragment Velocity (fps)	Weight of Largest Fragment (lbs)	Total Number of Fragments	Average Fragment Weight (lbs)	Weight of 95% Confidence Level Fragment (lbs)
A	4053.50	0.23	604.18	0.01	0.05
B	4866.18	0.17	1179.39	0.01	0.03
C	5202.93	0.09	812.99	0.00	0.02
D	4009.99	0.11	582.73	0.01	0.02

## 5.0 CONCLUSIONS

Methods for predicting the fragmentation characteristics of a cased explosive have been presented. These methods are applicable only for primary fragments resulting from a high-order detonation of a cylindrical casing with evenly distributed explosives in direct contact with the casing. For casings that are not uniform in thickness or diameter along the entire length, the casing should be modeled using a series of equivalent cylinders. When modeling such casings, particular attention should be given to ensuring that the total explosive contained in the model is within 0.5% of the actual total explosive weight.

The fragmentation characteristics calculated by the methods described herein may be used for a wide variety of purposes. The initial fragment velocity and a fragment weight may be used with a trajectory analysis to determine the range of the fragment. Penetration of these fragments into various materials may be calculated using the fragmentation characteristics and the appropriate material properties. Fragment striking energy at a given range may be calculated. Statistical evaluations may be done to determine the probability of a fragment of a given energy striking at a given distance.

These are only some of the uses for these fragmentation characteristics. Any evaluation requiring the primary fragmentation characteristics of a cased explosive may utilize the methods described above. These methods as detailed in HNC-ED-CS-S-98-1 have been approved by the Department of Defense Explosives Safety Board (DDESB) "for use in deciding Inhabited Building Distance (IBD) for primary fragments in site remediation activities."

## 6.0 REFERENCES

1. Army TM 5-1300, Structures to Resist the Effects of Accidental Explosions, November 1990.
2. HNC-ED-CS-S-98-1, "Methods for Predicting Fragmentation Characteristics of Cased Explosives", Structural Branch - U.S. Army Engineering and Support Center, Huntsville, January 1998.